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G-BIM framework and development process for integrated AEC design automation

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Abstract

The integration and automation of the whole design and implementation process has become a pivotal factor in Architecture, Engineering, and Construction (AEC) projects, especially regarding recent technological developments and emergent drivers in the field. Extant literature has highlighted a series of recurrent problems in process integration, especially at the conceptual design stage. This study presents the adoption of Generative Building Information Modelling (G-BIM) workspaces as an emerging technology. This has the potential to leverage conceptual design innovation in AEC projects. It builds upon the findings of an initial survey, and proffers a framework for using generative BIM workspaces at the conceptual design stage. This framework highlights the links and dependencies between generative/parametric tools and BIM applications to expedite information transition using generative tools primarily based on neutral BIM standards. Limitations of tools and approaches for providing accurate project information models are also captured in this framework. This paper demonstrates an overview of the G-BIM framework and the developed conceptual tool. Moreover, it reports on the challenges and opportunities associated with existing software applications. Findings reveal that the application of Generative Design (GD) can significantly enhance the design experience by assisting designers in the iterative generation of design alternatives and parameterisation processes. This framework purposefully integrates BIM with GD to enhance the design process at the conceptual design stage. This forms the rubrics for a working prototype which actively engages GD methods into a single dynamic BIM environment – the results of which will be presented in later works.

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Keywords: AEC; automation; BIM; computational design; generative design; parametric design

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1. Introduction

In AEC design practices, designers often put considerable [unnecessary] effort into design solution generation, often going through repetitious stages in order to seek viable solutions. Currently, designers usually take advantage of computational support such as Computer Aided Design (CAD) and BIM at later stages. However, during the early stages of the design process, decision making is a vital part of solution generation. The degree of automation through the design process is of great importance to the procurement of design alternatives. Cognisant of this, it is acknowledged that the use of generative systems as a design automation system at the early design stages could be very helpful for presenting viable [defendable] solutions quicker and more efficiently than conventional approaches. However, this should not obfuscate the need to satisfying the requirements of requirements capture, information modelling and data management; especially as projects are becoming increasingly more complex. Given this, multi-criteria design problems can be considered through the application of GD, the outcomes of which offer new innovative benefits to designers (and the design team).

Designers in current AEC projects, make use of advanced visualisation and modelling techniques ostensibly in the later stages of design, which often results in losing some the design knowledge of early conceptual phase (which is the origin of most of major decisions). Rahimian et al. [1] linked this problem to the non-intuitive interface of the conventional CAD tools which make them unsuitable for supporting the type of reasoning and cognition which appears during conceptual design phases. To tackle this problem, Lee et al. [2] recommended the application of parametric design interfaces as a new pattern in CAD and BIM, as the mechanisms are capable of producing design alternatives controlled by certain rules or limits, regardless of modelling and visualisation skills of designers. This approach proved beneficial for developing designers' creativity by equipping (providing) designers with synectics as an technique for forming ideas [3] and supporting the design process through the unproblematic generation of design alternatives [4] through altering various design parameters and observing (and reflecting on) the results in real-time [5]. To address these problems, the development of a 'Generative BIM workspace' to provide design creativity, fluidity, and flexibility by the application of generative design approach was proposed by Abrishami et al. [6]. Using such an integrated platform (plan), this work considered the information relevant to the design requirements as the input to the system and the design algorithms as the design output. They also regarded this platform integration helpful for designers to solve complex multi-criteria design problems.

This research presents a G-BIM framework and conceptual tool, developed in part using a questionnaire survey conducted by Abrishami et al.[7]. The survey aimed to explore different User Requirements Specifications (URSs) and various angles of integration of generative design algorithms to the existing BIM platforms, and to assist in identifying the conceptual framework's requirements for the G-BIM platform to maximise the efficiency of design teams and outline a new method for BIM applications to support throughout the design process; i.e. from the very early conceptual design stages to final detailed design phases.

This paper introduces a new approach for supporting conceptual design by incorporating GD into the BIM applications. A genotype of the design within a BIM application is proposed to allow the designer to give rise to new design alternatives by changing the pre-defined parameters with respect to the design constraints and requirements. Then the design team amend and improve the population of generated designs by the application of BIM capabilities. This method enables users to make use of BIM capabilities (such as collaboration, simulation, parametric features, etc.) through design. An overview of the framework and the conceptual developed tool is subsequently presented and defended. This paper initially describes the integration of the framework, and then each element of the proposed framework is presented in Section 4. The conceptual tool development process is also discussed as part of the supportive rationale. G-BIM adopts the same approach as conventional and existing design processes. Although G-BIM can help support and develop design creativity, fluidity, and flexibility; it brings about minimal changes to the common design process. Therefore, relevant information to the design requirements forms the system input, and the design algorithm generates the design output. The suggested system offers a design solution based on input data (site data, constraints, and requirements); and during the conventional design process the same data is taken into consideration by the designer. G-BIM can make full use of the potential of two existing individual generative systems; in particular, employing parametric change management of BIM applications - which changes dynamically according to the generative mechanism attached the generated model(s).

2. Background study

The focus of contemporary AEC design projects is increasingly moving from an architecture with aesthetical emphasis towards performance-based (structure, environment, construction, socioeconomically and cultural, etc.) architecture [8]. This shift in design attitude is inviting architecture to adopt new technologies that can support this transition. AEC designers started adopting technology from industrial design, mechanical engineering and product developments, where performance tended to play a crucial role, as well as adopting new computational design methods such as generative and parametric approaches, isomorphic surfaces, kinematics and dynamics, topological spaces etc. Given these changes and new inertia, this research explores the potential of a BIM design environment integrated with new computational design methods in order to maximise their opportunities. G-BIM exploits generative design for the creation of alternatives at the early design stages; especially, the existing parametric algorithms used in BIM tools for modifying the chosen alternatives, including change management during the late design stages up to the construction phase.

3. Methodology

During the development of the theoretical foundations of this study, a mixed-method approach was considered appropriate for understanding the construct relationships, albeit with special emphasis placed on qualitative techniques (to enable a broad and deep understanding of the current state of computational support used during the conceptual design phase). Bespoke empirical assessment techniques were employed to investigate design protocols (quantitatively), in order to determine measures of diversity, time-related events and derived design processes. This was considered important in order to support statistical outcome associated with design protocol data. This research therefore endeavoured to "seek clues" through perceptions of the design support tools' 'quality' and 'appropriateness' by investigating design protocols and artefacts. The research used process modelling concepts to develop a multi-disciplinary computational framework containing three main levels; process metal-level, process model, and development. This paper presents the process model stage of the project and highlights the potentials of the developed framework at the process meta-level phase.

The conceptual framework was developed using a process-centred environment for describing and evaluating the evolving software process [9]. This development process consists of three levels: meta-process modelling, process model, and development iteration. During the meta-level, the required information and key concepts were gained and classified to provide guidance for the development process [10]. Thereafter, the actual framework will be analysed, compiled and populated through interviews and observations from experts in BIM and GD. The development process will be achieved using a new design methodology based on Schön's "*reflective practitioner*" theory [11], Fitts's "*motor learning*" theory [12], and then verifying its effectiveness with empirical data. The research will adopt '*sequential mixed method research',* which starts with a qualitative approach and continues with quantitative approach (or vice versa). This study will follow Creswell's [13] guidelines in designing the sequential mixed method research by pursuing a single research aim. This paper presents only the meta-level of the project in order to highlight the potential of the proposed framework. The research narrative is purposefully aligned to tease out both the philosophical underpinnings of design theory continuum *per se,* matched against the practical constructs of research practice (including the technology and tools used to deliver this).

This paper builds on the work of Abrishami *et al.* [7], which conducted a detailed study using qualitative approach to adopt process modelling to develop a conceptual framework for Generative BIM Workspace. This paper presents part of an ongoing research study investigating the automation of conceptual design by integrating of GD and BIM as the central conduit; particularly by comprising both design method and computational architecture. This is postulated as being able to improve BIM's performance during the conceptual architectural design process. The research aim focuses on examining the feasibility and applicability of integrating GD and BIM. The main focus of this paper is therefore on the formulation, implementation, and presentation of G-BIM to support the conceptual design automation through a generative process. The first part of this paper explains the constructs of this research, including presenting the detailed framework, potential, and barriers. The second part of the paper reports on the tool interface and development. It also discusses how this framework could overcome the inherent problems.

4. G-BIM Framework

Integration of generative tools with information modelling combined with advanced 3D knowledge-rich systems is creating new potential for designing and coordinating amongst various stakeholders in AEC [14]. The use of GD can be defined as exploitation of parameters created at the early design stages. Since the generated solutions to the design problem (population of design alternatives) are the results of an algorithm (consisting design constraints, routines, and data files) by changing the inputs of the algorithm, the final design would be altered accordingly, like creating a basic model based on '*Routines'*, and generating different design alternatives by adjusting very basic design parameters.

Using this approach, the design character to be generated can be defined by the design team in order to reach an appropriate level of variability. When G-BIM is used, a large number of design alternatives (solutions) can be studied by the design team through the generation of the initial information mapped by the design team along with G-BIM's generative mechanisms. All the modifications take place in the central BIM software using the advanced BIM modelling features. The following section demonstrates how the G-BIM framework is used to develop the preliminary conceptual tool.

5. Development

Recent technological advancement in building design typically involves several conflicting criteria needs to be considered from the early stages of design. Therefore, design processes represent complex multi-criteria problems that require structured and systematic definition and exploration of the underlying design spaces and relating sub-solutions [15-18]. The BIM concept and relating technologies play important role here by providing a comprehensive digital representation of a building throughout the entire design phase and the subsequent operation. Considering advanced computational support tools for AEC design and construction which provides comprehensive support throughout late design up to construction and maintenance, there is a vital need for continues support and automation by filling the BIM systems' gap at the conceptual design stage.

This research's activities address four main phases. First it develops understanding and synthesis of state of the art computational support at AEC conceptual design; special attention is to be put on coherent automation solutions for building design and construction process. Thereafter, the targeted BIM/GD environment (for the need of various AEC designers at conceptual design stage) is justified. The G-BIM prototype is developed afterward to be used in demonstration activities. At the final stage of the research, the prototype within demonstration activities will be tested to diagnose and troubleshoot. Software design can differ from every other kind of design as:

- It has a dynamic product (software application);
- Software applications are some combinations of instructions and actions which are taken by the computers and are relatively invisible;
- Software applications often can be extremely complex and difficult to be understood;
- The stability of software applications is usually fluctuating so that a minor error in the codes can easily stop the whole system from working. It includes iterative emergence of various problems introduced by preceding solutions.

The aforementioned phase is the development of G-BIM Model. The main viewpoint is to have model that can generate a variety of design alternatives that differ in overall organisation and configuration with relevant level of details. The overall research task is presented in Fig. 1.

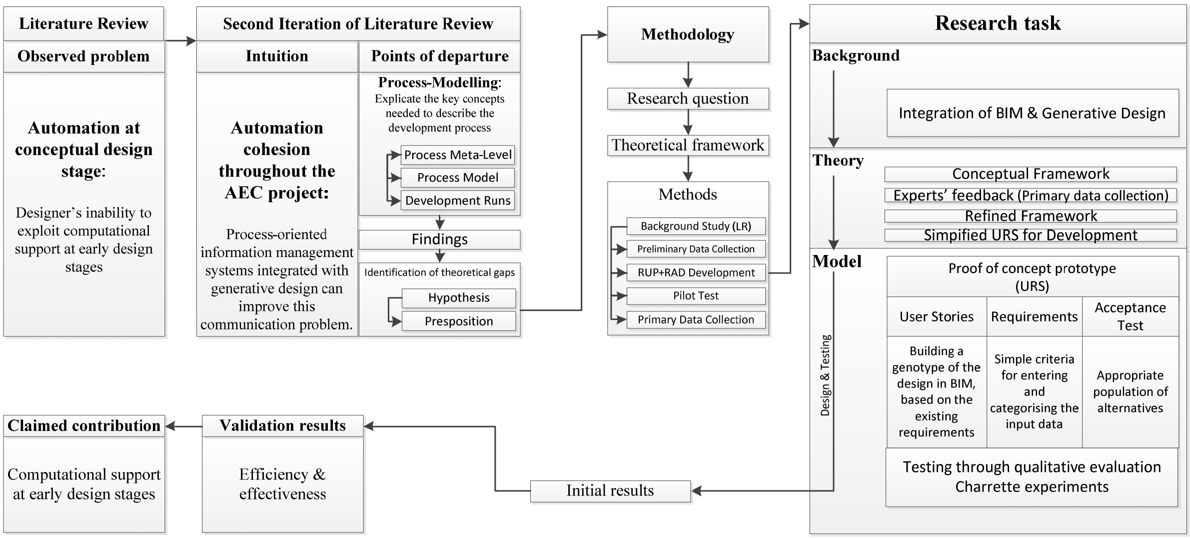

Fig. 1. Overall research Task

This project will follow a mixed Rational Unified Process (RUP) and Rapid application development (RAD) methodology for development (Fig. 2).

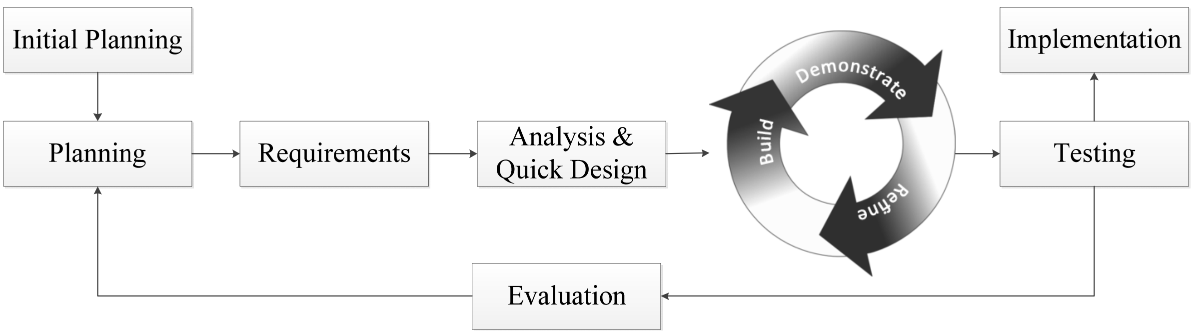

Fig. 2. Adopted RUP+RAD Development Process

6. Demonstration

The research adopts Janssen's evolutionary design approach [19], comprising design method and software system. As it is shown in G-BIM framework (Fig. 3), the proposed method is described in three phases; coding, generation, and modification. Coding phase is formed by routines and data-files. At the routine coding stage a generative process is defined with the capability of metamorphosing a genotype into a phenotype (like generating a 3D model of a design). At the data-file coding stage design context and constraints are specified. The generation system uses the Industry Foundation Classes (IFC) for representation of the generated designs. Using IFC model, make the representation of the information-data associated with the model available for using in advance analysis and simulation features of BIM application. Using the G-BIM, an existing BIM application (Autodesk Revit) is used at the modification phase. As the generation system is integrated with Revit, designer(s) can make use of its advanced modelling and analysis features. The generative evolutionary design assists designers through the early design stages, while the BIM parametric capabilities provide a direct relation to physical production process (construction). The presented example illustrates how G-BIM supports and enhances conceptual design through a flexible exploration of design solutions using a fully automated BIM system. The generated models interact with the BIM parameters and information data.

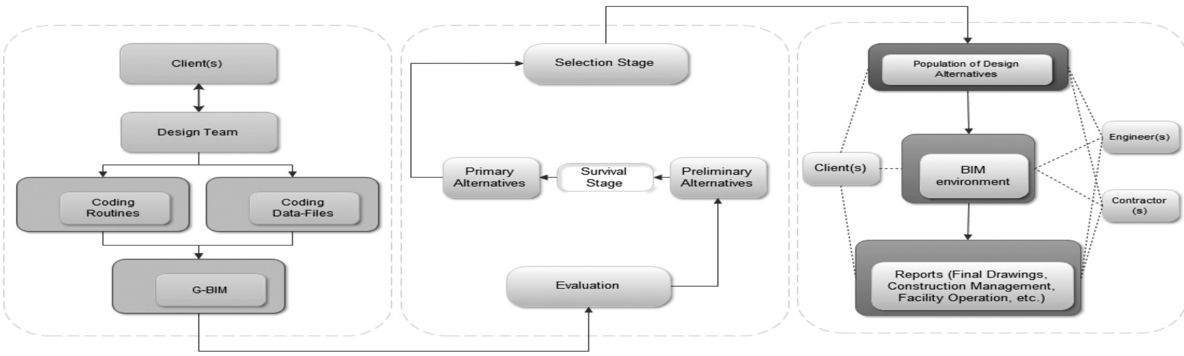

Fig. 3. G-BIM framework

The system will be developed using a programming language embedded in Revit, allowing the generative process to make direct use of Revit modelling functions. Moreover, the Revit will also be used for visualisation, with all feedback from the evolutionary process being displayed in the system interface. There are evolutionary systems developed [20] using AutoCAD and Sun's systems [21] integrated with MicroStation. G-BIM captures the information associated to the users' way of designing as well as design requirements, and simplifies the process of mapping this information by using Visual Dataflow Modelling (VDM). Moreover, it supports designers' interactions throughout the different design phases. Also there has been several attempts to make a link between generative and parametric tools and BIM tools like Geometry Gym, to enable exchange of generative tool models primarily using neutral BIM standards like SDNF, CIS/2, and IFC2x3 [22]; but due to limitations of generative tools in providing accurate information models, these solutions often fail to provide an overall enhanced solution (to some extent); whereas, it is intended that the proposed system will enhance BIM applications for both generating and visualising forms. Thus, the evolutionary system will be developed and fully integrated in the BIM environment (Figure 4).

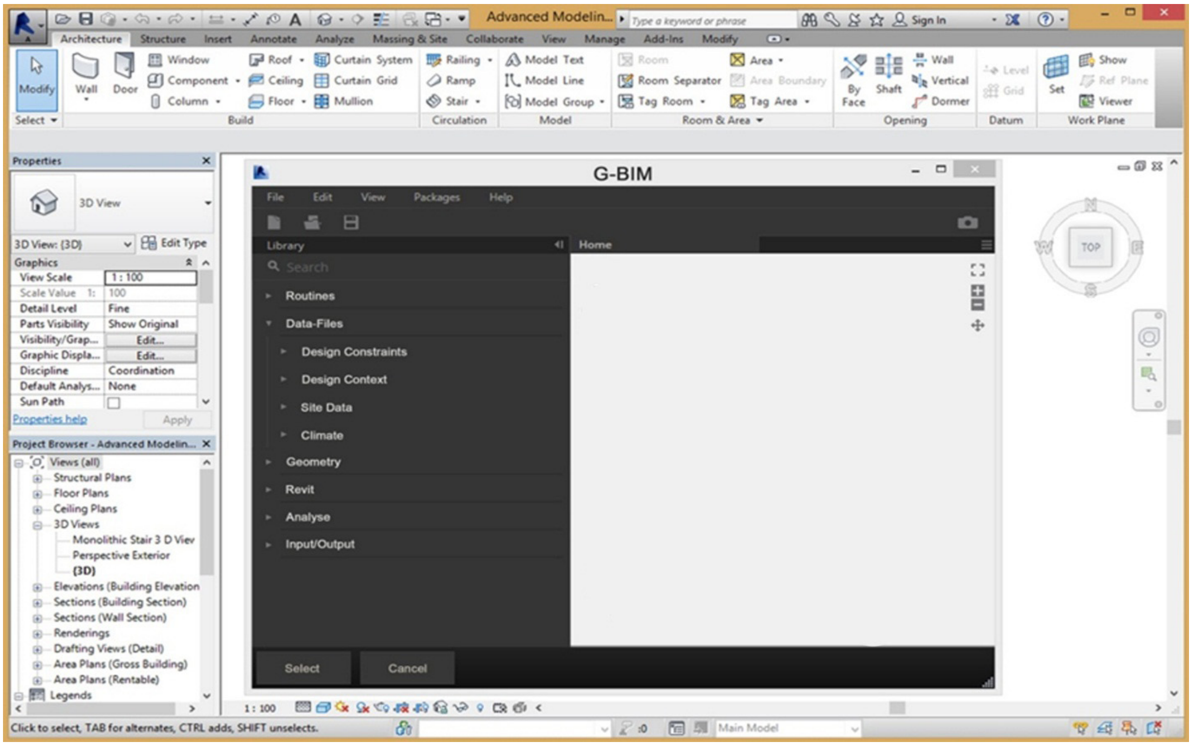

Fig. 4. Conceptual Tool Interface

7. Conclusion

The paper presented a valuable set of rubrics for discussion in order to support automation in conceptual design stage. The paper presented a single, flexible, and dynamic 3D environment conceptual prototype which covers a wide range of architectural design requirements through the design process. G-BIM was developed based upon previous research, including Abrishami *et al.* conceptual framework [6], and Abrishami *et. al.* [7] questionnaire survey. G-BIM has the potential to enable automation at the conceptual design stage, by analysing a large number of possible design solutions. Moreover, G-BIM is capable of filling the gap in the current AEC projects, and meets the required automation level throughout the design and construction by its innovative integrated approach.

Not only does the proposed system bridge the gap in existing BIM processes, but it also attempts to provide a meaningful roadmap for further exploratory studies of this nature – especially cognisant of the ever-increasing levels of project complexity and interconnected detailed design information. The developed framework and conceptual tool will be used to develop a final prototype which actively engages generative design methods into a single dynamic BIM environment. This study contributes to extant knowledge in this area by providing a ‘stepping stone’ for digital integration of all stages of an AEC project, especially concerning the implementation of BIM Level 3 (Cloud).

References

[1] Rahimian, F.P., Ibrahim, R., Wirza, R., Abdullah, M. T. B., & Jaafar, M. S. B. H.., Mediating Cognitive Transformation with VR 3d Sketching During Conceptual Architectural Design Process. Archnet-IJAR, International Journal of Architectural Research, 2011. 5(1): p. 99-113..

[2] Lee, J., Gu., N., Ostwald, M., and Jupp, J., Understanding Cognitive Activities in Parametric Design. In J. Zhang and C. Sun (Eds.), Global Design and Local Materialization , 2013, Springer Berlin Heidelberg. 369: p. 38-49.

[3] Blosiu, J. O., Use of synectics as an idea seeding technique to enhance design creativity. Paper presented at the Systems, Man, and Cybernetics, 1999. IEEE SMC '99 Conference Proceedings. 1999 IEEE International Conference on, 1999.

[4] Kim, Y. S., and Kang, B. G., Personal Characteristics and Design-Related Performances in a Creative Engineering Design Course. Paper presented at the the 6th Asian Design Conference, Tsukuba, Japan, 2003.

[5] Goulding, J.S. and F.P. Rahimian, Industry Preparedness: Advanced Learning Paradigms for Exploitation, in Construction Innovation and Process Improvement, A. Akintoye, J.S. Goulding, and G. Zawdie, Editors. 2012, Wiley-Blackwell: Oxford, UK. p. 409-433.

[6] Abrishami, S., Goulding, J., Ganah, A., and Rahimian, F. P. (2013) Exploiting Modern Opportunities in AEC Industry: A Paradigm of Future Opportunities. 2013. American Society of Civil Engineers(AEI) 2013: p. 321-333.

[7] Abrishami, S., Goulding, J. S., Ganah, A., and Rahimian, F. P., Integration Of BIM and Generative Design to Exploit AEC Conceptual Design Innovation, 2014. International Conference on Innovative Technologies in Construction (ITC) 2014.

[8] Roudavski, S., Towards Morphogenesis in Architecture. International journal of architectural computing, 2009. 07(03): p. 345-374.

[9] Finkelsteiin, F., Software Process Modelling and Technology. Jeff Kramer and Bashar Nuseibeh (Eds.). 1994, John Wiley & Sons, Inc., New York, NY, USA.

[10] Rolland, C., A comprehensive view of process engineering, in Advanced Information Systems Engineering, B. Pernici and C. Thanos, Editors. 1998, Proceedings of the 10th International Conference CAiSE'98, B. Lecture Notes in Computer Science 1413, Pisa, Italy. Springer Berlin Heidelberg. p. 1-24.

[11] Schön, D.A., The reflective practitioner : how professionals think in action. 1983, New York: Basic Books.

[12] Fitts, P.M., Perceptual--motor skill learning. In Categories of human learning, ed. A.W. Melton. New York, NY, 1964, Academic Press.

[13] Creswell, J.W., Research Design: Qualitative, Quantitative, and Mixed Method Approaches. Second ed. 2002, London, New Delhi: SAGE Publications. 246.

[14] Kocaturk., T., and Medjdoub., B., Distributed Intelligence In Design. Hardcover edition,2011, Wiley-Blackwell.

[15] Bazjanac, V., IFC BIM-based methodology for semi-automated building energy performance simulation. Paper presented at the CIB-W78 25th International Conference on Information Technology in Construction Santiago, Chile. 2008.

[16] Lewis, K. E., Chen, W., & Schmidt, L., Decision Making in Engineering Design, 2006. New York: ASME Press.

[17] Papamichael, K., LaPorta, J., and Chauvet, H., Building Design Advisor: automated integration of multiple simulation tools. Automation in Construction, 1997. 6(4): p. 341-352.

[18] Ross, A. M., and Hastings, D. E., The tradespace exploration paradigm. Paper presented at the Paper presented at the INCOSE International Symposium, Rochester, USA. 2005.

[19] Janssen, P., A Generative Evolutionary Design Method. Digital Creativity, 2006. 17(1): p. 49-63.

[20] Frazer, J.H. and J. Connor, A conceptual seeding technique for architectural design , Proceedings of International Conference on the Application of Computers in Architectural Design and Urban Planning (PArC79), AMK Berlin. 1999: pp. 425-434.

[21] Sun, J., Frazer, J. H., and Mingxi, T., Shape optimisation using evolutionary techniques in product design, Computers and Industrial Engineering, 2007. 53(2): p. 200-205.

[22] Mirtschin, J., Engaging Generative BIM Workflows, IABSE-IASS conference, London, 2011.